Power over SPE (PoSPE) Industrial HAT++ Add-on for Raspberry Pi

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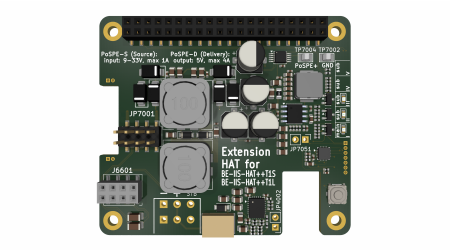

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Proprietary PoSPE board enabling power sourcing and delivery over Single Pair Ethernet (SPE), derived from established design approaches and industry practices.

This board extends BE-IIS HAT++ 10BASE-T1S and 10BASE-T1L HATs by enabling Power over Single Pair Ethernet (PoSPE). It is fully transparent to the BE-IIS HAT++ ecosystem, does not affect stackability, and instead enables power delivery for stacked systems, supporting seamless system integration and scalable system expansion.

Key Features

- PSE (source) and PD (sink) capability
- Up to 1 A over SPE
- 9–33 V operating range
- Regulated 5 V output (RSP supply)
- Up to 4 A output current
- Over-voltage, under-voltage, and over-current protection
- Reverse polarity protection
- Current sensing via I^2C
- ESD and transient protection
- RoHS compliant
- Quality component suppliers

Product Description

The PoSPE HAT is a Raspberry Pi HAT+ compliant interface board providing DC power coupling to the Single Pair Ethernet data line via an integrated low-pass filter. It supports current measurement via I^2C, includes voltage and current protection for the power source, and provides a regulated +5 V supply for the Raspberry Pi.

Applications

- PoSPE evaluation
- Prototyping
- Industrial network evaluation
- Education and laboratory use

Contents

1 Introduction

The BE-IIS HAT++ PoSPE Industrial HAT is a Raspberry Pi HAT+ compliant interface board enabling power delivery and sourcing over Single Pair Ethernet (SPE) for industrial and laboratory environments.

The board supports both Power Sourcing Equipment (PSE) and Powered Device (PD) operation, providing up to 1 A at 9–33 V on the SPE delivery interface.

On the system side, the received power is converted into a regulated 5 V rail using a high-efficiency DC/DC converter (LMR33640, Texas Instruments) [5], providing up to 4 A output current. This enables reliable supply of the Raspberry Pi, stacked HATs, and additional external equipment.

The available power budget also enables system expansion beyond the host platform, including PoSPE multidrop configurations, particularly in combination with BE-IIS-HAT++T1S-RevB and BE-IIS-HAT++T1L-RevB boards.

Power delivery and input protection are implemented using an integrated eFuse and monitoring device (TPS26600, Texas Instruments) [6], providing voltage and current supervision on the delivery path.

An INA226 current and voltage monitor [4] is used to measure the delivered power to the Raspberry Pi, enabling precise system-level power monitoring via I^2C.

The input stage includes a resettable fuse (PTC) and multiple TVS diodes to protect against transient events and over-voltage conditions in the PoSPE path.

The HAT is designed for evaluation, prototyping, and system integration of power over SPE applications.

As part of the BE-IIS HAT++ ecosystem, the board supports stacking and can be combined with additional communication and interface modules.

The HAT is fully compliant with the Raspberry Pi HAT+ specification [11] and supports advanced HAT++ features such as multi-board stacking and automatic system configuration.

2 Design Resources

All design files and software resources are publicly available.

HTML **Product Page**
https://www.be-iis.eu/products/BE-IIS-HPP-PoSPE_B/

PDF **Datasheet (PDF)**
https://www.be-iis.eu/products/BE-IIS-HPP-PoSPE_B/datasheet.pdf

PDF **Schematic (PDF)**
https://www.be-iis.eu/products/BE-IIS-HPP-PoSPE_B/schematic.pdf

HTML **Layout & BOM (Interactive)**
https://www.be-iis.eu/products/BE-IIS-HPP-PoSPE_B/ibom.html

STL **3D Model (STEP/STL)**
https://www.be-iis.eu/products/BE-IIS-HPP-PoSPE_B/model.zip

GIT **GitHub Repository**
https://github.com/be-iis/be-iis-installer

GIT **Installer Script**
https://github.com/be-iis/be-iis-installer/blob/main/scripts/install/install-all.sh
newpage

3 Hardware Configuration

The BE-IIS-HAT++PoSPE enables power delivery over a Single Pair Ethernet (SPE) data line, extending standard Raspberry Pi platforms with integrated power injection or extraction capabilities.

It allows a standard Raspberry Pi platform (e.g. Raspberry Pi Zero or Raspberry Pi 3/4/5, excluding Compute Module variants) to supply or receive power over the same two-wire SPE connection used for data communication.

Power interfacing is realized via the dedicated termination header, enabling seamless interaction with compatible BE-IIS SPE interface HATs (e.g. 10BASE-T1L or 10BASE-T1S). When combined, the PoSPE HAT can inject power into the SPE link or extract power from it, depending on the system configuration.

The design ensures transparent integration into the BE-IIS HAT++ ecosystem without affecting stacking capabilities or communication behavior.

3.1 Main Features

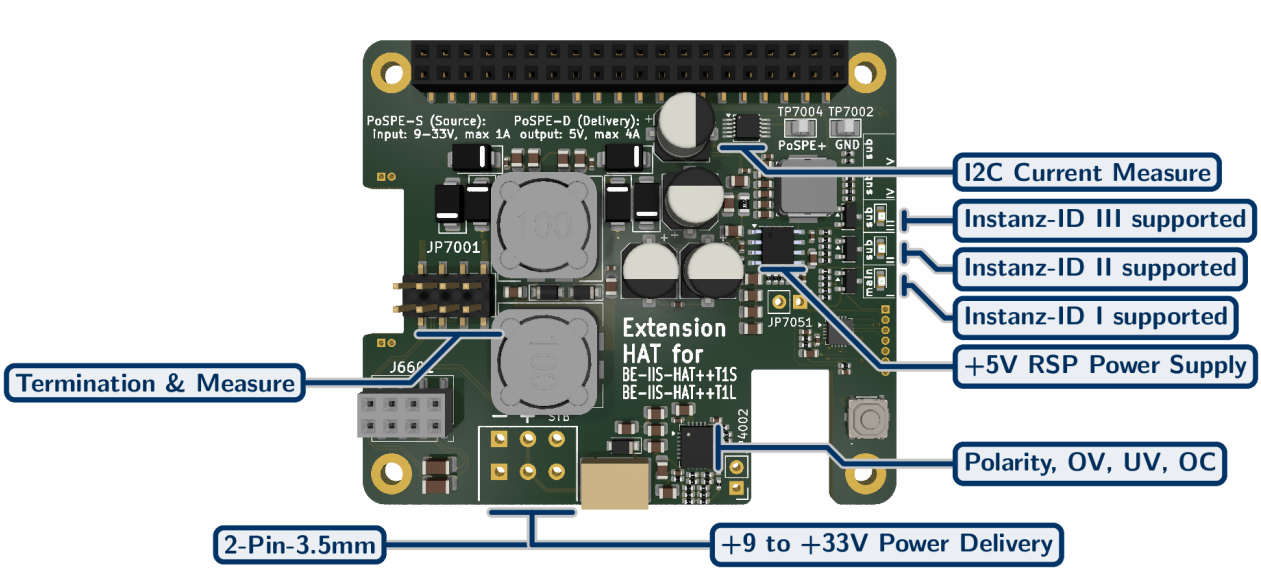

Figure 1: BE-IIS-PoSPE top view with annotations

Power Management Devices

- Supplier: Texas Instruments
- TPS26600 (eFuse with OVP/OCP) [6]
- INA226 (I^2C voltage/current monitor) [4]
- LMR33640 (step-down DC/DC converter) [5]

I^2C Interface

- 7-bit base address: 0b100000xx
- `xx` depends on the Instance ID of the base-board

Power Delivery

- Input voltage: 9–33 V
- Over-voltage protection (OVP)
- Under-voltage protection (UVP)
- Over-current protection (OCP)
- Reverse polarity protection

Power Source

- Regulated +5 V supply for Raspberry Pi
- Up to 4 A output current
- Current measurement via I^2C

SPE Line Polarity

- Integrated rectifier for polarity-independent operation
- Up to 1 A continuous current

3.2 Block Diagram

The block diagram shown in Figure 2 is simplified. It illustrates the power domains, isolation barriers, main functional blocks, and principal signal paths.

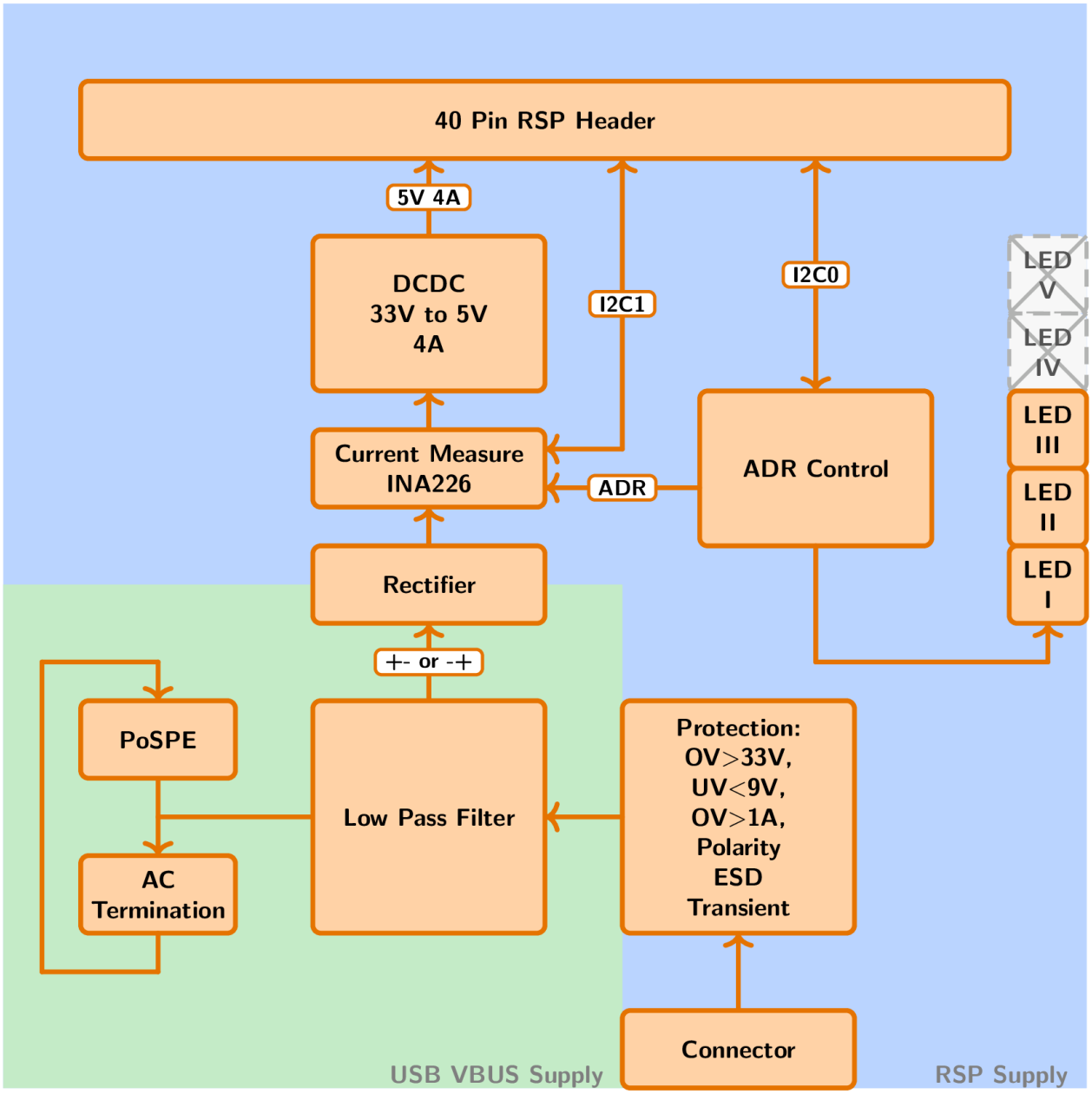

Figure 2: Simplified block diagram

3.3 Operating Mode and System Integration

The PoSPE board must be configured to match the instance mode of the connected base HAT.

This configuration is performed via the onboard mode selection (push-button).

When the instance mode is aligned, the PoSPE board operates as an extension of the baseboard and shares its system configuration.

This approach ensures:

- Consistent operation within the BE-IIS HAT++ ecosystem
- Correct integration into the HAT+ / HAT++ configuration flow of the baseboard
- Reliable operation in stacked configurations

The PoSPE board does not occupy a separate instance within the HAT++ system. Instead, it operates as part of the connected BE-IIS base HAT.

3.4 Interfaces

The Single Pair Ethernet (SPE) interface is implemented according to the applicable IEEE 802.3 standard for SPE.

For data transmission, the signal direction within the single twisted pair is irrelevant. The PHY automatically handles signal polarity and communication, so no manual configuration is required.

For Power over Single Pair Ethernet (PoSPE), no fixed polarity (positive or negative conductor assignment) is defined. The device incorporates an internal bridge rectifier at the power input. Therefore, the supply polarity applied to the SPE pair does not matter.

As a result, cable polarity is irrelevant for both SPE data transmission and PoSPE power delivery.

Standard single twisted-pair cabling compliant with the respective SPE specification is recommended. The maximum cable length depends on the selected SPE standard and data rate.

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3.5 Galvanic Coupling

The BE-IIS HAT++ PoSPE board does not provide galvanic separation. The interface is galvanically connected to the host system and all connected subsystems.

Important: When used in combination with a BE-IIS base HAT that provides galvanic separation, the PoSPE board bridges this isolation barrier. As a result, any existing separation of the baseboard is electrically bypassed.

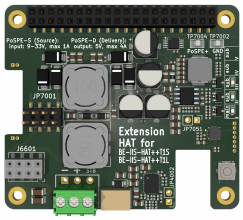
This must be considered in system design, as it may affect isolation, EMC behavior, and protection against ground potential differences.

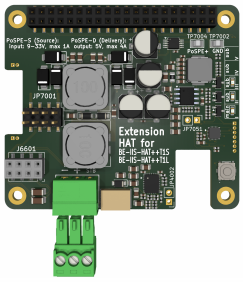
The board is intended for functional power delivery applications. If galvanic isolation is required at system level, appropriate external measures must be implemented.

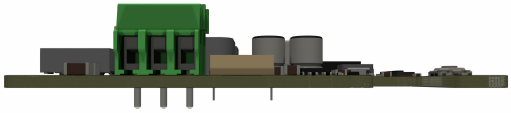
3.6 Connectors

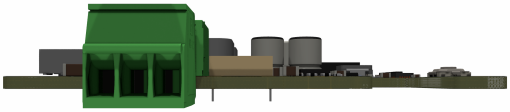
Connector J7001 provides the dedicated power input for the *Power over SPE (PoSPE)* functionality. It allows the connection of an external power supply (e.g. a laboratory power supply) to inject power directly onto the Single Pair Ethernet (SPE) bus.

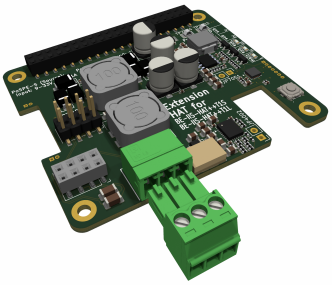
This enables the board to operate as a **power sourcing device**, supplying connected SPE nodes over the same two-wire data line. The interface is designed for flexible evaluation and system integration, ensuring controlled and reliable power delivery to the SPE network.











Description:
3-pin 3.5 mm rising cage screw terminal block
Optimized for One-HAT-Operation

Option1:
Phoenix Contact PT 1,5/3-3,5-H
Order Code: 1984620 [**??**]

Option2:
Wuerth Elektronik WR-TBL 300VAC 10A 3P
Order Code: 691214110003 [**??**]

Note: or equivalent component with compatible mechanical and electrical specifications
Pinning:

- Pin 1: GND (negative power)
- Pin 2: V_{IN} (positive power input)
- Pin 3: PD_EN (optional, force low to disable power delivery)

Description:
3-pin 3.5m mm PCB header and connector
Optimized for Stacked-HAT-Operation

Option1:
PCB Header: Phoenix Contact - MC 1,5/ 3-G-3,5 [**??**]
PCB Connector: Phoenix Contact - MC 1,5/ 3-ST-3,5 [**??**]
Order Code: 1844223(Header), 1840379(Connector)

Option2:
PCB Header: Wurth Electronic - WR-TBL 300VAC 12A 3P [**??**]
PCB Connector: Wurth Elecztronic - WR-TBL 300VAC 10.5Am Vertical 26-16AWG [**??**]
Order Code: 691305140003(Header), 691361100003 (Connector)

Pinning:

- Pin 1: GND (negative power)
- Pin 2: V_{IN} (positive power input)
- Pin 3: PD_EN (optional, force low to disable power delivery)

3.7 Signal Polarity and Wiring Orientation

The USB Type-C connector is fully reversible and can be inserted in either orientation without affecting functionality [8].

3.8 Current Measurement

The current measurement is implemented downstream of the rectifier stage on the PoSPE power path.

An INA226 current and voltage monitor [4] is used to measure both the input voltage and the current flowing from the SPE lines into the DC/DC converter supplying the Raspberry Pi.

The I^2C slave address of the INA226 is derived from the instance ID of the connected baseboard. The address configuration is summarized in Table 1.

Instance ID	Binary	Hex
I	0b1000000	0x40
II	0b1000001	0x41
III	0b1000100	0x44

Table 1: I^2C slave addresses depending on baseboard instance ID.

The device is connected to the Raspberry Pi via the `I2C1` interface.
The I^2C pull-up resistors are provided by the baseboard operating in Instance Mode I.

3.9 DC/DC Converter

The DC/DC converter steps down the input voltage of up to $33\,\mathrm{V}$ to a regulated $5\,\mathrm{V}$ output rail.
The converter is based on the LMR33640 [5] and provides up to $4\,\mathrm{A}$ output current, enabling reliable supply of the Raspberry Pi, stacked HATs, and additional external loads.
The converter can be disabled via jumper JP7051.

3.10 Protection

Input Power Protection (Connector J7000)

- Undervoltage protection: $V_{\text{in}} < 9\,\mathrm{V}$
- Overvoltage protection: $V_{\text{in}} > 33\,\mathrm{V}$
- Overcurrent protection: $I_{\text{in}} > 1\,\mathrm{A}$
- Reverse polarity protection

If the input voltage is within the valid operating range, the protection stage enables the power path and applies the corresponding voltage to the SPE data lines.
The local Raspberry Pi is supplied via the DC/DC converter, provided that the converter is enabled.
In the event of an overcurrent condition, the protection device (TPS26600) [6]disconnects the power path. After shutdown, the device periodically attempts to re-enable the output (auto-retry / hiccup mode) until the fault condition is removed.
The protection stage can be enabled or disabled via jumper JP4002.
In addition, the input stage includes ESD protection and transient voltage suppression (TVS) to improve robustness against electrical disturbances on the PoSPE interface.

3.11 Termination

The BE-IIS-PoSPE-HAT++ provides access to the SPE lines via the termination header. By default, no termination is applied on the HAT itself.
Termination can be enabled using jumper JP7001. This allows the board to be configured either as a bus end node (with termination enabled) or as an intermediate node (with termination disabled).

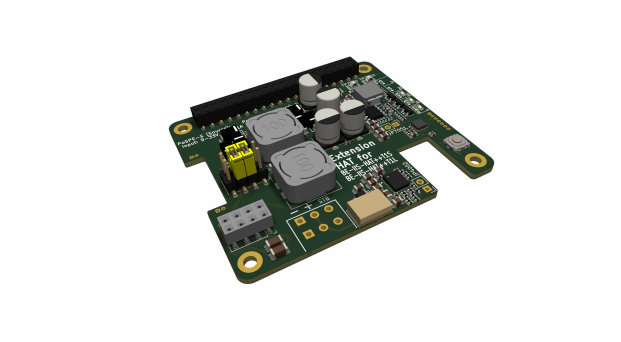


Figure 3: JP7001 jumper configuration with SPE termination enabled. The highlighted jumpers indicate bus end node configuration.

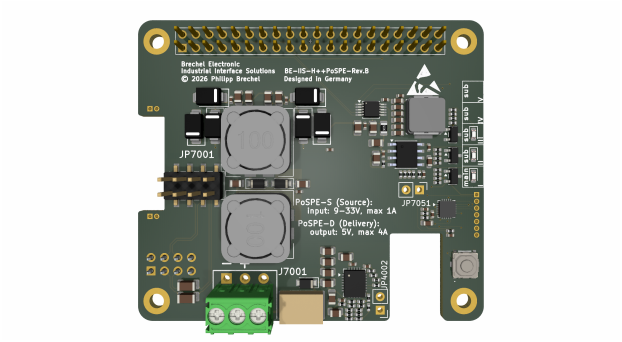


Figure 4: JP7001 jumper configuration with SPE termination disabled. Open jumpers indicate intermediate node configuration.

3.12 Low-Pass Filter

The circuit includes two common-mode chokes arranged in series: one operating in differential mode and one in common mode. They are placed sequentially in the signal path.
Transient voltage suppression (TVS) diodes are implemented to provide protection against voltage spikes and surge events.
The resulting low-pass filter characteristic attenuates the high-frequency data signal components and separates the data signal from the SPE supply.
The filter topology is based on the design recommendations provided in Microchip Application Note AN1848 [9].

4 Software and System Configuration

The BE-IIS-HAT++ system provides a unified platform for fast system integration.

- Predefined drivers and kernel modules
- Support for prebuilt modules and custom kernel builds
- Ready-to-use build and configuration scripts
- Centralized software repository [TODO]
- Typical setup time below a few minutes

After installation, the system can be used without further software modification.

5 Electrical Characteristics

5.1 PoSPE Delivery Voltage

Parameter	Min	Typ	Max	Unit
Input Voltage	9.0	–	33.0	V
Input Current	–	–	1.0	A

5.2 Raspberry Power-Delivery

Parameter	Min	Typ	Max	Unit
Output Voltage	4.8	5.0	5.2	V
Output Curren	–	–	4.0	A

6 Environmental Conditions

6.1 Conditions

Condition	Min	Max
Operating Temperature [°C]	-40	+85
Storage Temperature [°C]	-40	+105
Relative humidity [%]	5	95

Table 2: Operating conditions

6.2 Usage

Condition	Parameter
Usage	indoor
Pollution degree	2
Operating altitude	up to 2000 m

Table 3: Operating usage

6.3 EMC and Environmental Compliance (Preliminary)

The standard version of the board is provided without formal EMC or safety certification.
The hardware design is developed with consideration of commonly applied IEC standards, including:

- **ESD immunity:** IEC 61000-4-2
- **Electrical fast transient (EFT/Burst):** IEC 61000-4-4
- **Surge immunity:** IEC 61000-4-5
- **Conducted RF immunity:** IEC 61000-4-6
- **Radiated RF immunity:** IEC 61000-4-3
- **EMC immunity (industrial):** IEC 61000-6-2
- **EMC emission (industrial):** IEC 61000-6-4

These standards are not verified for the standard product variant.
Compliance with specific standards, test levels, or safety requirements is not guaranteed unless explicitly specified.
If defined EMC or isolation requirements are provided, application-specific validation, testing, and certification can be supported. Upon request, product variants with validated performance, including labeling, certification, and test reports (e.g. Hi-Pot testing), can be delivered.

7 Delivery

The product is delivered as a partially assembled kit intended for final user assembly. Mechanical accessories and connector components required for standard evaluation and stacked operation are included.

Order Code	BE-IIS-HPP-PoSPE
Condition	Assembly kit
Status	Partially assembled
Included Items	1× BE-IIS-HPP-PoSPE-PCBA-FT 4× M2.5x16 mm spacers 2x Jumper 1× 2×20 pin stackable header 1× 2×4 pin stackable header
REACH & RoHS	Compliant with EU Directive 2011/65/EU and REACH Regulation (EC) No 1907/2006

Table 4: Delivery condition and included parts

Figure 5: Delivery condition

8 Mechanical

8.1 Board Format

- Form factor: Raspberry Pi HAT+
- Mechanical dimensions: Raspberry Pi HAT compatible [11]
- Mounting hole pattern: Raspberry Pi HAT compatible [11]
- Stackszize: 15mm

9 Assembly

This product is delivered as a kit and requires basic soldering and mechanical assembly.

9.1 2x20-Pin Main Connector

The 2x20-pin connector provides the interface to the Raspberry Pi. For proper HAT functionality, the connector must be assembled carefully.
A stackable 2x20-pin header is included in the delivery and is recommended for most applications, especially when using the BE-IIS HAT++ stacking system.

- Mount the header on the top side of the PCB (component side)
- The socket side faces down towards the Raspberry Pi

Alternatively, a standard (non-stackable) pin header may be used if stacking is not required.
Soldering instructions:

- Use a suitable soldering iron with adequate temperature control
- Ensure good ventilation and avoid inhaling solder fumes
- Heat both the pad and the pin simultaneously, then apply solder
- Solder each pin individually and ensure proper wetting
- Avoid excessive solder to prevent large solder cones, which may affect stacking capability

Proper alignment of the connector is important to ensure mechanical compatibility with the Raspberry Pi and other HATs.

9.2 2x4-Pin SPE Connector

The 2x4-pin SPE connector J6601 is designed to mate directly with the corresponding SPE terminal header on the baseboard.
For proper operation, the termination jumper on the baseboard must be removed and instead placed at connector JP7001.
The connector is not polarized and can be inserted in either orientation. However, it must be mounted on the correct side of the board to ensure proper mechanical and electrical connection with the mating connector on the baseboard.

9.3 Spacer

To ensure mechanical stability and correct stacking height, spacers must be installed.

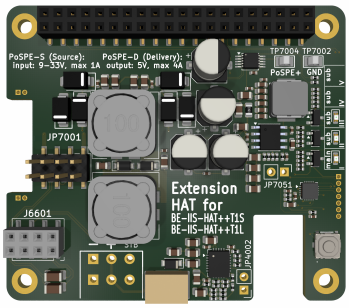
- Recommended spacer height: 15 mm
- Fix the PCB using appropriate screws and spacers
- Ensure stable mechanical mounting to avoid stress on the connector

The spacers define the stacking distance and provide mechanical fixation of the HAT.

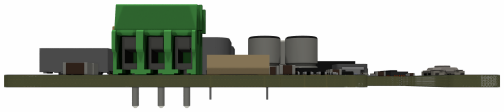
9.4 Board Overview

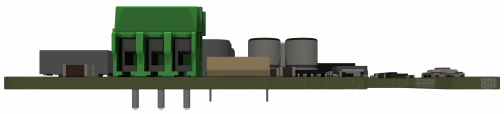
10 References

1. NXP SC16IS752 Datasheet
2. FTDI FT234XD Datasheet
3. Texas Instruments ISO734x Datasheet
4. Texas Instruments INA226 Datasheet
5. Texas Instruments LMR33640 Datasheet
6. Texas Instruments TPS26600 Datasheet
7. USB 2.0 Specification
8. USB Type-C Cable and Connector Specification
9. Microchip AN1848- Using Power over Data Line functionality in 10BASE-T1S Systems
10. NXP I²C-bus Specification and User Manual
11. Raspberry Pi HAT+ Specification
12. BE-IIS Installer (Software and Setup Tools)
13. Schematic, PCB-Viewer, BOM, 3D-Model

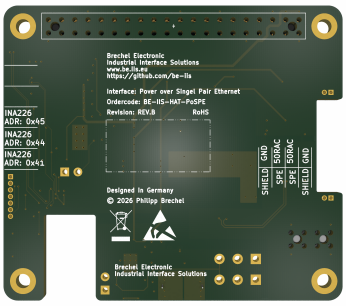


Top view

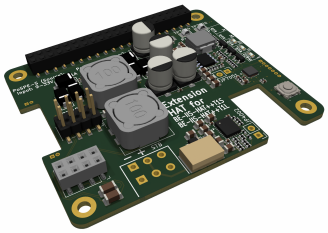




Front view



Bottom view



Side view

Figure 6: BE-IIS-HPP-PoSPE – mechanical overview

11 Revision History

Revision	Date	Description
A.00	2026-02-12	Initial draft
B.00	2026-05-05	First version of B

Company Information

Manufacturer

BE-IIS welcomes technical feedback, suggestions and improvement ideas. Business inquiries, cooperation requests and distribution opportunities are welcome.

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Languages	`German and English`